BIOLOGY, ECOLOGY, AND MONITORING OF THE PENTATOMIDAE (HETEROPTERA) SPECIES COMPLEX ASSOCIATED WITH TREE FRUIT PRODUCTION IN WASHINGTON

BY

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The members of the Committee appointed to examine the thesis of PETER SCOTT MCGHEE find it satisfactory and recommend that it be accepted.

CHAIR

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Abstract

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Several species of Pentatomidae (stink bugs) feed on pome and stone fruits in Washington. Feeding by *Euschistus conspersus* Uhler and *Chlorochroa ligata* (Sayii) results in sunken areas on the fruit, 1/4 to 1/8 inch in diameter that appear corky beneath the skin. Orchards in Chelan County with high infestations of stink bugs suffered significant loss due to cullage of damaged fruit. These orchards are surrounded by host plants that play a major role in stink bug development. *Euschistus conspersus* and *C. ligata* were regularly found on mullein, bitterbrush, and currant throughout all sites in 1996 and 1997. The development of *E. conspersus* was investigated at 4 constant temperatures and a lower developmental threshold was determined to be 12ºC. These species are univoltine in Washington and are attacked by several species of natural enemies, especially egg parasites. Surveys of parasites determined that 60% of stink bug eggs, in native habitats, are parasitized between late June and early July; this coincides with peak stink bug oviposition. Sampling strategies were developed to evaluate pest populations levels during the season. Two traps, the Jug and Fisher designs were determined to be effective in monitoring pest populations. Suggestions are made for further research.

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GENERAL INTRODUCTION

The use of broad spectrum insecticides (BSI) to control pest populations in Washington pome fruit orchards has increased slightly since 1989 (Beers and Brunner 1991, Anonymous. 1995). This is the result of several factors including: a reduction in the number of insecticides available resulting in more frequent use of fewer products, a lack in new registrations, and a reduction in the effectiveness of registered products (Beers et al. 1993). Additionally, programs using BSI have been questioned because of the destruction of natural enemies of targeted pest species and the resurgence of secondary pests formerly managed by now absent natural enemies (Benbrook, 1996).

Pheromones represent a promising alternative tactic for controlling primary insect pests, such as codling moth, *Cydia pomonella* (Linneaus), in pome fruit orchards in Washington (Gut et al. 1996, Knight 1995, Brunner et al. 1996). However, a pheromone-based pest management (PBPM) program represents a drastic departure from current integrated pest management (IPM) strategies that have continued to rely heavily on BSIs. Control decisions in PBPM programs become more complicated and site-specific in response to localized pest problems. One of the greatest challenges to a PBPM is the management of secondary pests which may reside outside of the orchard and only invade and cause damage at specific times of the year. The most notable examples are true bugs (Heteroptera) including the Miridae (plant bugs), Rhopalidae (scentless plant bugs), and Pentatomidae (stink bugs).

The stink bugs, family Pentatomidae, are members of the Order Hemiptera, suborder Heteroptera. They occur in the superfamily Pentatomoidea which is represented in North America by five families: Scutellaridae (shieldbacked bugs), Corimelaenidae (negro bugs), Cydnidae (burrower bugs), Acanthosomatidae (acanthosomatids), and Pentatomidae (stink bugs) (McPherson 1982). The Pentatomidae are world wide in distribution with approximately 760 genera and 4100 species known, making it the fourth largest family of Heteroptera (Schuh and Slater 1995). The majority of economically important stink bugs belong to the subfamily Pentatominae (Panizzi 1997).

Stink bugs are broadly oval or shield-shaped, and range in size from 4 to 20 mm in length. They have a segmented beak that arises from the front of the head and wings that lie flat on the abdomen, with the first pair leathery basally and membranous distally (Borror et al. 1989). The antennae are five segmented, occasionally four segmented with three segmented tarsi. The large scutellum is typically triangular-shaped. Nymphal dorsal abdominal scent glands occur dorsally and are paired between terga 3-4, 4-5, and 5-6 while scent glands are paired ventrally on the metathorax of adults. The ovipositor is plate-like, and the eggs are barrel-shaped with a detachable cap (pseudoperculum). Stink bugs are paurometabolous, meaning that they undergo a gradual metamorphosis with immature and adult stages occurring in the same environment.

Many species of stink bugs are phytophagous and therefore occur in grassy or herbaceous habitats. They feed by sucking plant juices from immature fruits and seeds with stylate mouthparts. Adults over-winter beneath leaf litter or other ground debris (McPherson 1982, Bordon et al. 1952). Mating begins in the spring and eggs are laid in clusters on leaves and twigs of host plants. In North America, stink bugs are generally uni- or bivoltine. In the pome fruit regions of the Sierra foothill counties in California, *Euschistus conspersus* Uhler is bivoltine (Borden et al.

1952). Nymphs emerge from eggs with assistance of an egg burster, a sclerotized process inside the egg that splits the pseudoperculum. Immature stink bugs pass through five nymphal stages. During the first nymphal instar, siblings congregate near the eggs and remain inactive. Feeding commences during the second stadium.

It has been reported that stink bugs rely on native plant hosts to reproduce. In Virginia, *Euschistus sp*. attacking peach do not reproduce on the fruit, but develop on white-top fleabane, common mullein, and horseweed (Woodside 1947). Similarly, Schoene and Underhill (1933) found that *Acrosternum hilare* (Say) preferred wild plants to cultivated crops, and that these wild hosts appeared to be necessary for the insect to maintain itself in high numbers. In California, stink bugs detrimental to deciduous fruit trees feed on weed hosts early in the spring and move into orchards when the native plant hosts dry (Borden et al. 1952).

Most stink bugs are phytophagous, and many are recognized as pests of food crops. The green vegetable bug, *Nezara viridula* (Linnaeus), attacks a wide range of vegetable and field crops including soybean, sunflower, maize, and tomato (Goodyear 1977). In Hawaii, *N. viridula* injures the fruit of macadamia nuts (Jones and Caprio 1994). The stink bugs *Oebalus pugnax* (Fabricius) and *Scotinophara coarctata* (Fabricius) cause severe injury to rice in the Southern United States and Asia, respectively (Way and Wallace 1984, Rombach et al. 1986). Several species attack pecans including *N. viridula*, *Euschistus sp*., and *Leptoglossus spp*. (Yates et al. 1991). *Acrosternum hilare, Chlorochroa ligata* (Say), *Thyanta custator* (Fabricius), *E. conspersus, Euschistus servus* (Say), and *Euschistus variolarius* (Palisot) attack pome and stone fruits in North America and *Plautia stali* (Scott) affects fruit trees in Japan (Whitmarsh 1917, Schoene and

Underhill 1933, Woodside 1946, Borden et al. 1952, Rings 1957, Anonymous 1978, and Tachikawa et al. 1977). Not all stink bugs cause damage to food crops. The predatory stink bugs *Perillus bioculatus* (Fabricius) and *Podisus maculiventris* (Say) have been evaluated as potential biological control agents of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Biever and Chauvin 1992).

Historically, chemical controls have been used to combat these pests. The insecticides Thiodan (endosulfan), Lannate (methomyl) , monocrotophos, and methyl parathion have been used to control *N. viridula* in soybean (Goodyear 1977, Orr et al. 1989). However, several pyrethroid insecticides (lambda-cyhalothrin, syfluthrin, tralomethrin, and cypermethrin) are superior to methyl parathion in controlling stink bug populations in soybean (McPherson et al. 1995). In Texas, carbaryl, methyl parathion, and malathion have been used to control the rice stink bug, *O. pugnax* (Way et al. 1990).

There is a great deal of observational and anecdotal information on stink bugs in tree fruits, but little on pest management practices. Historically, stink bug populations were controlled with chemicals including lindane, parathion, dieldrin, and dichlorodiphenyltrichloroethane (DDT) (Borden et. al. 1952). More recently, Thiodan (endosulfan) (Warner, 1993), Cygon 267 (dimethoate), and Carzol SP (formetanate hydrochloride) were reported as possible stink bug controls (Anonymous, 1978). Current stink bug management programs in Washington on pome and stone fruits rely on delayed-dormant sprays of endosulfan, dimethoate, or formetanate hydrochloride in the spring or late summer (Beers 1995). However, management of stink bugs with insecticides is difficult, especially when they invade orchards late in the growing season, a time when the choice of chemical controls is limited by pre-harvest interval (PHI) considerations (Warner 1994). Additionally, repeat sprays are sometimes required if stink bugs continue to migrate into orchards from nearby native habitats.

Alternatives to BSIs for stink bug control include the entomopathogenic fungi, *Beauveria bassiana* (Bals.), *Metarhizium anisopliae* (Metsch.) and *Paecilomyces lilacinus* (Thom.). These have been evaluated for control of the black bug of rice, *Scotinophara coarctata,* with some success (Rombach et al. 1986). Several new insecticides are poised for registration on tree fruit crops including tebufenozide, fenoxycarb and spinosad (Brunner, personal communication, Brunner 1996). Although no studies have been conducted on pestiferous stink bugs in pome fruits using tebufenozide, this compound did not adversely affect the predatory stink bugs, *Podisus nigrispinus* (Dallas) and *P. maculiventris* (Say) (Hemiptera: Pentatomidae), in tests conducted by Smagghe and Degheele (1995). It is also unlikely that fenoxycarb, a juvenile hormone mimic, will control stink bugs, and spinosad has not been tested against these pests (Bret et al. 1997).

Several species of stink bugs are recorded attacking pome (apple and pear) and stone (peach) fruits in North America (Whitmarsh 1917, Mundinger and Chapman 1932, Schoene and Underhill 1933, Woodside 1946, Borden et al. 1952, Rings 1957, Wilks 1964, Phillips and Howell 1980, Anonymous 1991, Beers et al. 1993, Warner 1993, 1994). However, no research has been published on stink bugs in Washington state since 1948 when they were reported attacking peach near Wenatchee, Washington (Borden et al. 1952).

Stink bugs feed on maturing fruit causing blemishes that result in down-grading. Feeding on peach results in severe scarring known as cat-facing (Woodside 1947) while injury to apple resembles, and therefore is confused with, the physiological disorders cork spot and bitter pit (Beers et al. 1993, Warner 1993, 1994). Symptoms on apple include small, dark sunken areas about 1/8- to 3/8- inch in diameter, usually located on the surface of the upper half of the fruit. Damaged pears have irregular dimpling around the stem resembling hailstone injury (Mundinger et. al. 1932). Internally, the injured flesh of apple and pear is described as being corky and white with damage extending into the fruit approximately 1/8 inch (Mundinger and Chapman 1932, Borden et al. 1952, Rings 1957, Wilks 1964). Feeding by other true bugs (Heteroptera) may result in injury similar to that caused by stink bugs (Anonymous 1991). Often, external injury to fruit is undetectable, but the damage is apparent after the fruit has gone to market or is processed in canneries, a condition that may result in fines to the producer (Borden et al. 1952, Wilks 1964). Severe injury has been reported to result in fruit drop (Mundinger and Chapman 1932).

Stink bugs are attacked by several species of natural enemies. They are parasitized by species in the family Tachinidae (Diptera) (Eger and Ables 1981, McPherson et al.1982). However, studies on the effects of tachinid parasites have mostly been limited to stink bugs occurring in soybean and alfalfa. Eggs of various stink bug species are attacked by chewing and sucking predators (Yeargan 1979) and parasitic wasps (Whitmarsh 1917, Mundinger and Chapman 1932, Schoene and Underhill 1933, Borden et al. 1952, Jubb and Watson 1971, Anonymous 1991). The parasites *Trissolcus euschisti* (Fouts) and *Telenomous podisi* (Ashmead) (Hymenoptera: Scelionidae) are recorded attacking the egg stage in the genera *Acrosternum* and *Euschistus* (Orr et al. 1986). *Telenomous utahensis* (Ashmead) is recorded attacking eggs in the genus *Chlorochroa* (Jubb and Watson 1971).

Pest management programs that rely on the use of BSIs generally have reduced activities of beneficial insects. Methyl parathion use in soybean negatively affects *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae), an egg parasitoid of *N. viridula* (Orr et al. 1989). Also, methyl parathion and carbaryl used in rice reduces the survival of *T. podisi* (Hymenoptera: Scelionidae), a parasitoid of *O. pugnax* eggs (Sudarsono et al. 1992).

Damage to fruit occurs primarily in orchards bordered by uncultivated land (Mundinger and Chapman 1932). Stink bugs are common in natural habitats surrounding orchards and on cover crops within orchards (Whitmarsh 1917, Borden et al. 1952, Phillips and Howell 1980, Anonymous. 1991, and Beers et al. 1993); however, weeds are more important as sources for stink bugs than cover crops (Woodside 1947). Migrating adults invade orchards and feed on the fruit. Injury to pome fruits is periodic and localized, although in severe cases a majority of the crop may be injured (Mundinger and Chapman 1932).

The purpose of this research was to Characterize the complex of stink bug species occurring in and around pome fruit orchards in Washington and to determine stink bug species primarily responsible for fruit injury and to investigate key aspects of stink bug development and population dynamics. Specific aspects of their biologies were investigated, including host plants utilized during development and when they moved from native habitats into orchards. Different sampling methods were used to monitor stink bug phenology. Different traps, in conjunction with an attractant, were evaluated as tools to monitor activity and movement of stink bugs into orchards. The development of one species, *E. conspersus*, was determined at different constant temperatures and lower developmental thresholds estimated. Parasitoids attacking stink bugs eggs were collected for identification and their activity throughout the season was determined.

CHAPTER 1

A SURVEY OF PENTATOMIDAE IN CENTRAL WASHINGTON FRUIT GROWING REGIONS

INTRODUCTION

The economic importance of stink bugs (Hemiptera: Pentatomidae) attacking deciduous fruits has long been recognized. In 1911, *Acrosternum hilare* (Say) was reported attacking peach in Ohio (Whitmarsh 1917) and during 1931 *E. variolarius* (Palisot) and *Euschistus euschistoides* (Voll) were observed attacking pear in New York (Mundinger and Chapman 1932). *Euschistus conspersus* Uhler is destructive to pome fruits in California (Borden et al. 1952). Wilks (1964) described *E. variolarius* as causing injury to deciduous fruits in the Pacific Northwest. In Washington, pome fruits have suffered injury similar to that caused by stink bugs in other fruit producing regions of the United States. Research was conducted in north-central Washington during the summer of 1995 to determine which species of phytophagous stink bugs were present and the host plants they utilized.

Observations of stink bugs indicate that native and cover-crop plants can serve as important hosts (Woodside 1947, Schoene and Underhill 1933). Host plants are important food resources for developing nymphs and therefore are a factor in determining their pest status on crops (Panizzi 1997). Mundinger and Chapman (1932) reported that the most severe injury to fruit occurred along orchard border rows adjoining woodlands or uncultivated areas. The preferred hosts of stink bug species reported injuring peach in Virginia were wild or uncultivated plants (Underhill 1934). Stink bugs may rely on a succession of wild hosts to reach sexual maturity. Adults hibernate under weeds or leaves of plants. In California fruit orchards with cover crops, *E. conspersus* Uhler prefers dry vegetation surrounding the trees (Borden et al 1952).

The seasonal development of the two most common stink bug species found in orchards, *E. conspersus* and *C. ligata*, was monitored in the pome fruit growing regions of north-central Washington during 1996 and 1997. The host plants utilized during their development and when they moved into orchards were investigated. Additionally, the development of *E. conspersus* was determined at different constant temperatures in order to determine estimates of a lower developmental threshold.

MATERIALS AND METHODS

Species complex

Surveys were conducted in 1995 to determine the stink bug complex in fruit producing regions of north-central Washington and to determine which of these species produce injury to apple and pear. Five regions were surveyed: Entiat River Valley, Wenatchee, Orondo, Lake Chelan, and Cashmere. Native vegetation surrounding orchards and orchard trees was sampled for presence of stink bugs. Herbaceous ground cover was sampled using a sweep net while a beat tray was used for surveying woody vegetation. Sweeping was conducted using a heavy duty cotton net (38 cm diameter x 94 cm handle). One swing of the net (2 m) equaled one sweep. The beating tray, a 2’ x 2’ cloth covered tray, was held beneath limbs of shrubs or trees which were then jarred three times with a 2’ length of 2” diameter radiator hose. Adult stink bugs and host vegetation were collected at each location from May through August, 1995. Voucher specimens from this survey were placed in the James Entomological Collection at Washington State University, Pullman. *Chlorochroa, Cosmopepla,* and *Thyanta* identifications were determined using species keys by Buxton et al. (1983), McDonald, (1986), and Rider and Chapin (1992). *Acrosternum* and *Euschistus* identifications were determined by Dr. Richard Zack, curator of the James Entomological Collection, Washington State University. Plant materials were identified using keys in Flora of the Pacific Northwest (Hitchcock and Cronquist 1996).

Phenology

In 1996, stink bug phenology was followed at four sites. One site was an orchard consisting of mixed pear varieties (Anjou, and Bartlett) planted on a 8’ x 14’ tree x row spacing located in a riparian habitat near Entiat, Washington, and is hence referred to as the Entiat Site. The other three sites were apple (Delicious) orchards located in a habitat of dry scrub-brush including bitterbrush, wild currant, sage, mullein, and blackberry. Two of these sites were located near Manson, Washington, and are hence referred to as the Craft and Dole Sites. The other apple site was located near Orondo, Washington, along the Columbia River approximately 15 miles north of Wenatchee and is hence referred to as the Orondo Site. Orchards at the Craft, Dole, and Orondo Sites were planted on a 15’ x 18’, 15’ x 18’, and 12’ x 19’ tree x row spacing, respectively.

Stink bugs were sampled from native vegetation (bitterbrush, wild rose, currant, mullein, red-osier dogwood, poplar, black berry, snowberry, and thimbleberry) surrounding orchards and on trees (apple and pear) within the orchards. Sampling was conducted weekly (May through August) using two techniques, visual inspection and beating tray. The visual inspection method consisted of counting all stink bugs occurring on a mullein plant, the entire plant being considered one sample unit. The beating tray, a 2’ x 2’ cloth-covered tray, was held beneath limbs of shrubs or trees which were then jarred three times with a 2’ length of 2” diameter radiator hose. Each tray was considered one sample unit. Twenty-five random samples were taken from each host plant at each site weekly. The numbers and life stages of each stink bug species were recorded along with the host plant on which they occurred.

In 1997, samples were made only in the fruit growing region around Lake Chelan. The Craft and Dole Sites were again sampled and a new one, the Naumes Site, was added. The Naumes orchard was located near Chelan, Washington, in dry scrub-brush habitat similar to the Dole and Craft Sites and had a tree x row spacing of 20’ x 20’. Sites were sampled from May through September using the same methodology as described for 1996.

Development

Euschistus conspersus individuals were reared from egg through adult stage at four constant temperatures; 21°C, 24°C, 27°C, and 30.5°C. Eggs were obtained from a laboratory colony of *E. conspersus* that had been initiated from adults collected in the field. The colony was maintained in one gallon paper cylinder ice cream-type containers with a sheet of plastic food wrap covering the top. Approximately 10 male and 10 female adult *E. conspersus* were maintained in each container. Adults were fed raw shelled peanuts, fresh green beans, and a sugar water solution. The sugar water solution was supplied in a 1 oz. Dixie® brand plastic creamer cup with a 1-inch long cotton dental wick inserted into the lid of the cup. A 2” x 8” paper strip was hung on the inside wall of the colony container as an oviposition substrate for females. The colony was maintained in a long-day photoperiod (16h:8h, L:D). The containers were checked daily to collect freshly laid eggs and to replace food. Sections of waxed paper containing individual egg masses were removed and placed in small plastic petri dishes (Falcon® #1006 50 x 9 mm) and placed in an incubator with a long-day photoperiod of (16h:8h, L:D). Incubator temperatures were maintained ± 0.5°C.

Egg masses contained between 10 and 14 eggs. These were collected daily, placed in a petri dish, and incubated at one of four temperatures. Samples were checked each day to monitor hatch. Following ecdysis, second instar nymphs were separated from siblings and reared individually in small plastic petri dishes (Falcon® #1006 50 x 9 mm) to the adult stage at a constant temperature. Each nymph was provided a diet of green beans and raw shelled peanuts after the first nymphal instar. Nymphs were checked daily to record molts to the next stage and mortality. Stink bugs were reared until 50 individuals successfully completed development to the adult stage at each of the four temperatures. The time (in days) required for each individual to complete each stage (egg and nymphal instars 1 through 5) was determined. The rate of development of each life stage, and egg to adult, was determined by taking the reciprocal of the days in the stage. An estimate of lower developmental temperature (T_0) for each stage was determined by plotting the average development rate for a stage against the rearing temperature using linear regression. Degree-days (DD) required for stage specific and total development were derived from the regression equation

$y = a + bx$, $T_0 = -a/b$, $DD = 1/b$, where y is the development rate at temperature x, and a and b are estimates of the y intercept and slope.

RESULTS AND DISCUSSION

Stink bug complex and phenology

Eight species of Pentatomidae were found in Chelan and Douglas counties in central Washington on uncultivated plants and pome fruits (Table 1.1). Less than 10 *Chlorochroa sayi* (StÅl) stink bugs were found during this survey, and all were collected outside of orchards. Likewise, *E. variolarius* was collected from only native vegetation. Four species, *E. conspersus*, *A. hilare*, *Chlorochroa ligata* (Say), and *Thyanta pallidovirens* (StÅl) were collected from native host plants and from trees in orchards.

Results of this survey suggest that four stink bug species may be responsible for injury sustained to pome fruits in north-central Washington. *Euschistus conspersus*, *A. hilare*, *C. ligata*, and *T. pallidovirens* occurred in orchards where fruit damage was observed or had been reported in the past. Three species, *E. conspersus*, *A. hilare*, and *C. ligata*, have been reported as causing injury to tree fruits in other regions of the United States (Borden et al.1952, Underhill 1934, and Anonymous 1991). *Thyanta custator* is reported as a pest of apples in California (Anonymous 1991); however, according to Rider and Chapin (1992) its range does not include the West Coast. This would suggest that *T. custator,* previously reported attacking fruits in California, may actually be *T. pallidovirens* which was found during my survey in Washington. Of these four stink bug species collected in orchards, *E. conspersus* and *C. ligata* were found more frequently than *A. hilare* and *T. pallidovirens.*

Euschistus variolarius is also reported as a pest of tree fruits (Wilks 1964), although it was never observed in fruit orchards during this survey. *Acrosternum hilare* was found at only one site, Entiat, an orchard surrounded by riparian habitat. One predatory stink bug species, *Brochymena sp.,* occurred both inside and outside of fruit orchards. *Cosmopepla integressus* (Uhler) had a close affinity with currant and was rarely observed on other native vegetation and never on fruit trees.

Sampling uncultivated plants surrounding orchards may provide fruit producers with important information on stink bug species present in the area and alert them to potential problems. A general pattern was observed with stink bugs invading orchards. *Euschistus conspersus* and *C. ligata* adults were collected on native vegetation during all summer months but were more abundant in June and August, Tables 1.2 and 1.3. Nymphs occurred in these areas during the same period. During August, greater numbers of adults were found in orchards, suggesting that immature development occurs on uncultivated plants outside of orchards and that stink bugs migrate into orchards when they mature. This pattern is similar to that reported for stink bugs in other fruit producing regions (Woodside 1947, Borden et al. 1952, Phillips and Howell 1980). Although these data indicated that both species in Washington are univoltine, Borden et al. (1952) reported that *E. conspersus* is bivoltine in California, and therefore the timing of control methods would not be similar for these two fruit producing regions.

Two habitat types dominate the fruit producing region of north-central Washington, dry-land and riparian. Vegetation in dry-land areas consisted of bitterbrush, currents, balsam root, sage, and rabbitbrush. Vegetation in riparian areas included cottonwood, red-osier dogwood, thimbleberry, snowberry, rose, and blackberry. *Acrosternum hilare* was found only in riparian habitats. *Euschistus* sp. and *T. pallidovirens* were found in dry-land and riparian habitats, while the *Chlorochroa* spp. occurred only in the dry-land areas. Plants in dry-land areas bloom during May, June, and early July. This vegetation dries in August, causing fruits and leaves to fall off of the plant. Adult stink bugs may invade orchards at this time because the vegetation remains succulent.

Tables 1.4 through 1.10 summarize the mean number of *A. Hilare*, *E. conspersus,* and *C. ligata* nymphs and adults found on host plants through each summer according to site. Although stink bugs were recovered from a wide variety of plants, relatively few stink bugs were found on asparagus, baby’s breath, balsam root, bigleaf maple, blackberry, cheat grass, dalmatian toadflax, elderberry, rabbitbrush, knapweed, service berry, and vetch. No stink bugs were found on sumac or sage.

Many *Chlorochroa ligata* were observed on bitterbrush in 1996 (Tables 1.7-1.9). The nymph stage constitutes the majority of these observations, with the greatest number occurring in July. The mean number of *C. ligata* nymphs found on bitterbrush in July was 14, 46, and 3 at Cashmere, Manson, and Orondo, respectively. Relatively few *C. ligata* were observed on other vegetation during that period. *Chlorochroa ligata* matures to the adult stage during August.

Euschistus conspersus occurred more frequently on mullein than any other plant. Adults constitute the majority of *E. conspersus* found on mullein during June and August. Nymphs were more prevalent in July. All developmental stages of *E. conspersus* were also found on currant and bitterbrush, but less frequently than on mullein. The number of *E. conspersus* adults increased in August similar to the pattern observed for C. ligata on bitter brush.

Phenology summaries for 1996 and 1997 (Table 1.11) indicate that *E. conspersus* primarily oviposited on mullein. Nymphs appear to develop on this plant continuously through to the adult stage. Populations of this species were also found on bitterbrush during each season but at lower levels than on mullein. Few *E. conspersus* were detected on currant. In contrast, *C. ligata* favored bitterbrush over mullein during early development but appeared to switch over to mullein as adults. Eggs of this species were not detected on any of the plants sampled. The relative absence of eggs may be due to undiscovered oviposition sites or difficulty in observing eggs on these plants. Leaves of currant and bitterbrush are relatively small, although they are very numerous on the plant. Mullein has large leaves, allowing easy visual detection of *E. conspersus* eggs. Eggs of each species is distinct and not easily confused with one another. This would rule out the possibility that *C. ligata* eggs were actually sampled and mistaken for *E. conspersus* eggs. Eggs of *E. conspersus* are creamy white or green with reticulations on the chorion and are oviposited in clusters of 12-14. Eggs of *C. ligata* appear finely punctate and are usually deposited in masses containing 22 eggs.

Euschistus conspersus and *C. ligata* were common on bitterbrush, mullein, and currant at all sites. These plants may entirely constitute the diet of these two stink bugs during development.

Because mullein occurs naturally around orchard borders and attracts large numbers of stink bugs, it may represent a potential trap crop. Removing these plants from along orchard borders or from within an established distance of orchards might also be one tactic to use to reduce fruit injury. However, this would be difficult to incorporate as a management tactic throughout a region because mullein occurs over large geographical areas. It might also be possible to conserve stands of mullein for purposes of monitoring the appearance of stink bug adults in late summer.

Neither species of stink bug was found on apple or pear during August when invasions occur. This may have been a result of inadequate sampling methods for these plants. Maturing fruit easily dropped from the limbs when jarred during beating-tray sampling and thus this technique was not used. Visual detection of stink bugs was also difficult because they move to the back side of fruit when approached. They were usually detected in flight.

Development

Stage specific development rates for *E. conspersus* are shown in Table 1.12. Parameters of linear regression (slope and y-intercept) describe the relationship between development and temperature for the egg and stadia 1 through 5. Mean development rates through the adult stage ranged from 55.3 days at 21^{o}C to 27.1 days at 30^{o}C. The minimum development threshold (T_0) was estimated as 12^{o}C. Survival to the adult stage was low, especially at the lower temperatures, ranging from 5.2% at 21^{o}C to 11.6% at 30.5^{o}C. Development rates were most rapid during the first, third, and fourth nymphal stages. The mean duration in days of the egg, third, and fifth stage was nearly double the time required for the other instars, (see Table 1.13).

The length of time required for *E. conspersus* to reach the adult stage, when maintained at constant temperatures, was 465 degree days. This indicates that there is only enough time for a single generation in north-central Washington. Although mating and oviposition might occur for a second generation, the phenology data does not indicate this. The number of stink bug nymphs declined in August, and those that did occur were in the 4th and 5th stadia. Peak oviposition for *E. conspersus* occurred in early June. Based on this starting point for degree days accumulated, adults were expected to begin appearing around 30 July. This closely correlated with the actual increase in the number of adults occurring around 15 July. The development model could be used as a tool to estimate when stink bugs reach the adult stage. This may assist crop pest consultants and fruit producers to determine optimal timing for application of pest control measures.

Several stink bug species were found in north-central Washington, including*: Euschistus conspersus, Euschistus variolarius, Chlorochroa sayi, Chlorochroa ligata, Acrosternum hilare, Thyanta pallidovirens, Cosmopeplae integressus*, and a predacious stink bug in the genus *Brochymena*. *Euschistus conspersus* and *C. ligata* were the most prevalent species found in and around fruit orchards. Although both species are pests of tree fruits in California (Borden et al. 1952), little was known of their life history in Washington. Understanding their phenology and development is the first step in learning how to manage these pests. Also, development of passive monitoring methods would reduce costs associated with monitoring these pests and indicate when stink bugs invade orchards. These pests are transitory and develop outside of orchards invading during periods when chemical controls are limited due to PHI restrictions. An alternative control tactic may include biological control measures, especially parasitoids attacking the egg stage of stink bugs.

Table 1.1. Incidence of stink bug species in north-central Washington according to host vegetation.

getation	*Euschistus conspersus*	*Acrosternum hilare*	*Chlorochroa ligata*	*Chlorochroa sayi*	*Thyanta pallidovirens*	*Euschistus variolarius*	*Cosmopepla integressus*	*Brochym a* sp.
pple	Ad, Ny	Ad	Ad		Ad			Ad
aragus	Ad, Ny				Ad			
’s breath	Ad							
am root	Ad							
af maple	Ad							
erbrush	Ad, Ny		Ad, Ny	Ad	Ad, Ny		Ad, Ny	Ad, Ny
ckberry	Ad, Ny							
at grass								
herry	Ad	Ad			Ad			
urrant	Ad, Ny		Ad, Ny		Ad, Ny		Ad, Ny	
on toadflax								
erberry	Ad, Ny							
ullein	Ad, Ny		Ad, Ny	Ad	Ad	Ad		Ad
Pear	Ad, Ny	Ad, Ny			Ad, Ny			Ad
oplar	Ad							Ad, Ny
bitbrush								
er dogwood	Ad, Ny	Ad, Ny			Ad, Ny			Ad, Ny
knapweed	Ad, Ny				Ad			
age								
iceberry	Ad	Ad, Ny						Ad
wberry	Ad	Ad, Ny			Ad, Ny			
umac								
bleberry	Ad	Ad						
etch	Ad							
d Rose	Ad, Ny	Ad			Ad, Ny		Ad	Ad, Ny

Ad = indicates the adult stage was found.
Ny = indicates the nymph stage was found.

Table 1.2. Mean number of *E. conspersus* and *C. ligata* adults and nymphs found in native habitats in north-central Washington 1996.

Site	Date	n	*E. conspersus* nymph Mean ± SEM	*C. ligata* nymphs Mean ± SEM	*E. conspersus* adults Mean ± SEM	*C. ligata* adults Mean ± SEM
Cashmere	31 May	3	0.00	0.00	0.00	0.00
	14 June	3	0.00	0.00	0.00	0.66 ± 0.66
	28 June	3	5.00 ± 2.51	0.00	11.33 ± 5.23	0.00
	12 July	3	7.33 ± 4.66	7.66 ± 4.90	5.00 ± 2.64	0.00
	26 July	3	10.66 ± 5.60	5.66 ± 4.17	4.00 ± 2.08	0.00
	9 August	3	13.66 ± 6.98	0.00	9.66 ± 5.23	0.00
	23 August	3	2.66 ± 1.45	0.00	6.33 ± 3.48	0.00
Entiat	31 May	3	0.00	0.00	0.00	0.00
	14 June	3	0.00	0.00	0.00	0.00
	28 June	3	6.33 ± 3.17	0.00	4.66 ± 1.20	0.00
	12 July	3	4.00 ± 4.00	0.00	7.33 ± 1.85	0.00
	26 July	3	5.33 ± 4.37	0.00	6.66 ± 2.60	0.00
	9 August	3	1.66 ± 1.66	0.00	3.33 ± 2.02	0.00
	23 August	3	3.33 ± 3.33	0.00	7.66 ± 0.88	0.00
Manson	31 May	3	0.00	0.00	0.00	1.33 ± 0.66
	14 June	3	1.33 ± 1.33	0.00	17.66 ± 13.71	0.33 ± 0.33
	28 June	3	17.66 ±10.39	8.00 ± 8.00	11.00 ± 2.51	0.33 ± 0.33
	12 July	3	15.00 ± 8.66	39.66 ± 19.23	16.33 ± 9.93	1.00 ± 0.57
	26 July	3	9.66 ± 4.84	19.66 ± 8.41	11.66 ± 5.54	13.00 ± 9.16
	9 August	3	1.00 ± 0.57	2.66 ± 2.66	8.66 ± 5.17	4.33 ± 4.33
	23 August	3	15.66 ± 13.71	0.00	16.33 ± 13.34	0.00
Orondo	31 May	3	0.00	0.00	0.00	0.00
	14 June	3	0.00	0.00	0.00	0.00
	28 June	3	6.66 ± 3.38	0.66 ± 0.66	4.66 ± 1.76	0.00
	12 July	3	5.33 ± 2.66	1.66 ± 0.88	4.66 ± 1.20	0.66 ± 0.33
	26 July	3	8.00 ± 4.04	0.33 ± 0.33	6.66 ± 5.17	0.66 ± 0.66
	9 August	3	2.66 ± 2.66	0.66 ± 0.66	9.00 ± 5.85	4.00 ± 1.08
	23 August	3	4.66 ± 4.66	1.00 ± 1.00	7.00 ± 5.00	2.66 ± 1.66

n = number of dates that samples were collected and pooled for the month

Table 1.3. Mean number of *E. conspersus* and *C. ligata* adults and nymphs found in native habitats in north-central Washington 1997.

ite	Date	n	*E. conspersus* nymph Mean ± SEM	*E. conspersus* adults Mean ± SEM	*C. ligata* nymphs Mean ± SEM	*C. ligata* adults Mean ± SEM
raft	29 May	4	0.00	12.59 ± 12.59	0.00	0.00
	15 June	4	0.00	0.83 ± 0.83	0.00	0.00
	30 June	4	10.07 ± 10.07	0.00	0.00	0.00
	15 July	4	15.11 ± 15.11	5.03 ± 5.03	9.47 ± 9.47	0.00
	30 July	4	0.00	5.87 ± 5.87	4.21 ± 4.21	0.00
	15 Aug	4	0.00	3.35 ± 2.22	1.57 ± 1.57	2.10 ± 1.05
	30 August	4	0.00	14.27 ± 14.27	1.05 ± 1.05	4.21 ± 4.21
ole	29 May	4	0.00	0.00	0.00	0.00
	15 June	4	0.00	10.91 ± 10.91	0.00	0.52 ± 0.52
	30 June	4	8.00 ± 8.00	10.07 ± 10.07	16.31 ± 16.31	2.11 ± 2.11
	15 July	4	46.33 ± 46.33	12.59 ± 12.59	15.79 ± 12.76	0.00
	30 July	4	35.00 ± 35.00	18.47 ± 17.23	25.26 ± 18.61	10.52 ± 8.27
	15 Aug	4	10.07 ± 10.07	29.51 ± 25.83	10.52 ± 8.99	25.79 ± 23.46
	30 August	4	0.00	42.23 ± 40.98	2.10 ± 2.10	35.26 ± 32.92
umes	29 May	4	0.00	0.00	0.00	0.00
	15 June	4	0.00	0.00	0.00	0.00
	30 June	4	11.66 ± 6.17	41.99 ± 41.99	0.00	0.00
	15 July	4	18.33 ± 8.37	11.75 ± 1.67	9.47 ± 9.47	0.00
	30 July	4	12.75 ± 5.52	9.44 ± 3.61	13.15 ± 7.75	4.21 ± 4.21
	15 Aug	4	5.00 ± 2.48	13.85 ± 13.03	6.31 ± 3.28	10.00 ± 10.00
	30 August	4	1.75 ± 1.18	18.89 ± 15.58	0.00	42.10 ± 38.95

n = number of dates that samples were collected and pooled for the month

Table 1.4. Mean number of stink bug nymphs and adults occurring on host vegetation and in the orchard at the Craft Site in Chelan County, Washington, 1997.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	4	0.0	0.3	3	0.0	0.0	3	0.0	0.0
Bitterbrush	*E. conspersus*	4	1.3	0.0	4	2.3	0.0	3	0.0	0.3
Currant	*E. conspersus*	4	0.0	0.0	4	0.0	0.0	3	0.0	0.0
Mullein	*E. conspersus*	4	0.8	0.0	4	16.0	3.5	3	10.0	6.7
Apple	*C. ligata*	4	0.0	0.0	3	0.0	0.0	3	0.0	0.0
Bitterbrush	*C. ligata*	4	0.0	0.0	4	6.5	0.0	3	1.7	1.0
Currant	*C. ligata*	4	0.0	0.0	4	0.0	0.0	3	0.0	0.0
Mullein	*C. ligata*	4	0.0	0.0	4	0.5	0.0	3	1.0	5.0

n = number of dates that samples were collected and pooled for the month

Table 1.5. Mean number of stink bug nymphs and adults occurring on host vegetation and in the orchard at the Dole Site in Chelan County, Washington, 1997.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	4	0.0	0.8	4	0.0	0.0	3	0.0	0.0
itterbrush	*E. conspersus*	4	0.0	0.0	4	11.0	0.5	3	2.0	1.3
Currant	*E. conspersus*	--	--	--	--	--	--	--	--	--
Mullein	*E. conspersus*	4	16.0	13.0	4	60.0	13.0	3	21.0	51.0
Apple	*C. ligata*	4	0.0	0.0	4	0.0	0.0	3	0.0	0.0
itterbrush	*C. ligata*	4	0.0	0.0	4	16.3	0.8	3	1.0	3.0
Currant	*C. ligata*	--	--	--	--	--	--	--	--	--
Mullein	*C. ligata*	4	7.8	1.8	4	16.0	5.5	3	11.0	55.0

n = number of dates that samples were collected and pooled for the month

-- data not obtained

Table 1.6. Mean number of stink bug nymphs and adults occurring on host vegetation at the Naumes Site in Chelan County, Washington, 1997.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	4	0.0	0.0	4	0.0	0.3	3	0.0	0.0
Bitterbrush	*E. conspersus*	4	0.0	0.0	4	1.5	1.8	3	1.3	1.3
Currant	*E. conspersus*	4	0.0	0.0	4	18.0	4.0	3	1.7	1.7
Mullein	*E. conspersus*	4	4.0	50.0	4	6.5	5.8	3	3.7	24.0
Apple	*C. ligata*	4	0.0	0.0	4	0.0	0.0	3	0.0	0.0
Bitterbrush	*C. ligata*	4	0.0	0.0	4	4.0	4.0	3	0.0	2.0
Currant	*C. ligata*	4	0.0	0.0	4	4.0	1.0	3	2.0	2.0
Mullein	*C. ligata*	4	0.0	0.0	4	4.0	4.0	3	2.0	2.0

n = number of dates that samples were collected and pooled for the month

Table 1.7. Mean number of stink bug nymphs and adults occurring on host vegetation at the Cashmere Site in
Chelan County, Washington, 1996.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	--	--	--	3	0.0	2.0	3	0.0	0.0
Bitterbrush	*E. conspersus*	3	0.0	1.3	3	9.0	1.5	3	0.0	0.0
Currant	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	--	--	--
Mullein	*E. conspersus*	3	0.0	3.7	3	10.3	9.6	3	5.0	3.0
Pear	*E. conspersus*	--	--	--	3	0.0	0.0	3	0.0	0.0
ed-osier dogwood	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	3	0.0	0.0
Snowberry	*E. conspersus*	--	--	--	3	0.0	0.0	3	0.0	0.0
Wild Rose	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	3	0.0	0.0
Apple	*C. ligata*	--	--	--	3	0.0	0.0	3	0.0	0.0
Bitterbrush	*C. ligata*	3	0.0	1.0	3	14.0	0.0	3	0.0	0.0
Currant	*C. ligata*	3	0.0	0.0	3	0.0	0.0	--	--	--
Mullein	*C. ligata*	3	0.0	2.0	3	3.0	0.0	3	0.0	0.0
Pear	*C. ligata*	--	--	--	3	0.0	0.0	3	0.0	0.0
ed-osier dogwood	*C. ligata*	3	0.0	0.0	3	0.0	0.0	3	0.0	0.0
Snowberry	*C. ligata*	--	--	--	3	0.0	0.0	3	0.0	0.0
Wild Rose	*C. ligata*	3	0.0	0.0	3	0.0	0.0	3	0.0	0.0

n = number of dates that samples were collected and pooled for the month

-- data not obtained

Table 1.8. Mean number of stink bug nymphs and adults occurring on host vegetation at the Manson Site in Chelan County, Washington, 1996.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	3	0.0	0.0	3	0.0	0.3	3	0.0	0.0
itterbrush	*E. conspersus*	3	0.0	3.3	3	4.3	3.3	3	0.0	0.0
Currant	*E. conspersus*	3	0.0	17	3	6.0	0.0	3	0.0	0.0
Mullein	*E. conspersus*	3	0.0	22..3	3	17.7	23.0	3	8.0	19.0
Apple	*C. ligata*	3	0.0	0.0	3	0.7	1.7	3	0.0	0.0
itterbrush	*C. ligata*	3	12.0	1.0	3	46.7	1.7	3	0.0	1.0
Currant	*C. ligata*	3	5.7	1.0	3	5.0	1.3	3	0.0	0.0
Mullein	*C. ligata*	3	2.0	0.7	3	15.7	7.0	3	8.0	13.0

n = number of dates that samples were collected and pooled for the month

-- data not obtained

Table 1.9. Mean number of stink bug nymphs and adults occurring on host vegetation at the Orondo Site in Douglas County, Washington, 1996.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Apple	*E. conspersus*	--	--	--	--	--	--	--	--	--
Asparagus	*E. conspersus*	3	0.0	0.0	3	6.7	4.7	--	--	--
Bitterbrush	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	1	0.7	0.3
Currant	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	--	--	--
Mullein	*E. conspersus*	3	0.0	62.0	3	4.0	32.0	1	9.3	13.3
Knapweed	*E. conspersus*	3	0.0	0.0	3	0.0	0.0	1	14.7	4.0
Apple	*C. ligata*	--	--	--	--	--	--	--	--	--
Asparagus	*C. ligata*	3	0.0	0.0	3	0.0	0.0	--	--	--
Bitterbrush	*C. ligata*	3	26.0	7.0	3	3.3	2.3	1	1.3	3.7
Currant	*C. ligata*	3	2.0	1.0	3	1.0	0.7	--	--	--
Mullein	*C. ligata*	3	0.0	0.0	3	0.3	0.3	1	0	0.7
Knapweed	*C. ligata*	3	0.0	0.0	3	0.7	0.3	1	0.3	0.0

n = number of dates that samples were collected and pooled for the month

-- data not obtained

Table 1.10. Mean number of stink bug nymphs and adults occurring on vegetation at the Entiat Site in Chelan County, Washington, 1996.

Plant	Species	n	June		n	July		n	August	
			nymph	adult		nymph	adult		nymph	adult
Bigleaf maple	*E. conspersus*	1	0.0	16.0	2	0.0	0.0	--	--	--
Bitterbrush	*E. conspersus*	2	0.0	1.5	3	4.0	5.0	1	1.0	1.0
Mullein	*E. conspersus*	2	0.0	2.5	3	5.0	3.0	1	1.0	2.0
Pear	*E. conspersus*	--	--	--	3	0.0	0.0	1	1.0	1.0
ed-osier dogwood	*E. conspersus*	2	1.3	11.3	3	1.0	1.0	1	0.0	0.0
Snowberry	*E. conspersus*	--	--	--	--	--	--	1	2.0	3.0
Thimbleberry	*E. conspersus*	2	0.0	1.0	3	3.0	1.0	--	--	--
Wild rose	*E. conspersus*	2	0.0	6.5	3	3.0	0.5	1	0.0	0.0
Bigleaf maple	*A. hilare*	1	0.0	0.0	2	0.0	0.0	--	--	--
Bitterbrush	*A. hilare*	2	0.0	0.0	3	0.0	0.0	1	0.0	0.0
Mullein	*A. hilare*	2	0.0	0.0	3	0.0	0.0	1	0.0	0.0
Pear	*A. hilare*	--	--	--	3	0.0	0.0	1	0.0	0.0
ed-osier dogwood	*A. hilare*	2	22.0	44.0	3	105.0	9.0	1	0.0	6.0
Snowberry	*A. hilare*	--	--	--	3	6.0	0.0	1	5.0	1.0
Thimbleberry	*A. hilare*	2	0.0	7.0	3	0.0	4.0	--	--	--
Wild rose	*A. hilare*	2	0.0	7.0	3	25.0	9.0	1	2.0	2.0

n = number of dates that samples were collected and pooled for the month
-- data not obtained

Table 1.11. Mean number (± SE) of *E. conspersus* and *C. ligata* eggs, nymphs, and adults occurring on host vegetation in north-central Washington during 1996 and 1997.

			E. conspersus			*C. ligata*		
Location	Plant	n	Egg	Nymph	Adult	Egg	Nymph	Ac
Cashmere	Mullein	7	5.71 ± 3.91	7.86 ± 3.05	10.43 ± 2.41	0	2.67 ± 1.76	0.67
	Bitterbrush	7	0	9.00 ± 3.21	8.27 ± 1.90	0	10.33 ± 5.24	
	Currant	7	0	0	0.86 ± 0.46	0	0	
Entiat	Mullein	7	--	--	--	--	--	
	Bitterbrush	7	0	6.43 ± 2.35	7.00 ± 1.77	0	0	
	Currant	7	--	--	--	--	--	
Manson	Mullein	7	13.43 ± 5.18	17.70 ± 6.98	37.00 ± 8.12	0	7.18 ± 4.29	4.27
	Bitterbrush	7	0	8.14 ± 2.72	6.43 ± 1.00	0	22.64 ± 12.12	1.18
	Currant	7	0	0	5.57 ± 1.81	0	0.64 ± 0.43	0.55
Orondo	Mullein	7	3.71 ± 2.41	7.14 ± 2.00	12.29 ± 2.44	0	0.17 ± 0.17	
	Bitterbrush	7	0	4.57 ± 2.22	13.29 ± 8.17	0	1.33 ± 0.62	0.83
	Currant	7	0	0	1.29 ± 0.42	0	0.67 ± 0.42	
Craft	Mullein	12	10.92 ± 5.91	10.92 ± 5.91	6.93 ± 3.75	0	0.29 ± 0.29	0.29
	Bitterbrush	12	0	0	3.36 ± 3.14	0	4.16 ± 2.70	0.29
	Currant	0	--	--	--	--	--	
Dole	Mullein	12	43.69 ± 19.73	26.60 ± 13.42	38.10 ± 11.01	0	16.80 ± 6.80	19.95
	Bitterbrush	12	0	0	1.26 ± 0.66	0	9.62 ± 4.29	1.29
	Currant	0	--	--	--	--	--	
Naumes	Mullein	8	10.00 ± 5.56	17.38 ± 3.49	45.99 ± 14.37	0	2.73 ± 1.48	15.50
	Bitterbrush	8	0	11.25 ± 2.64	3.47 ± 1.42	0	7.61 ± 3.49	0.29
	Currant	6	0	3.00 ± 1.16	7.14 ± 1.89	0	1.01 ± 0.75	0.29

-- plant did not occur at site

Table 1.12. Mean duration (days) of each life stage for *E. conspersus* maintained at four constant temperatures
in the laboratory.

Temperature	Egg	First	Second	Third	Fourth	Fifth	n	Mean[a] ± SEM
21	12.96	6.81	9.70	9.14	12.67	15.00	10843	66.28 ± 0.093
24	7.58	3.97	5.76	5.20	6.20	9.90	966	38.61 ± 0.064
27	6.98	3.72	5.43	4.87	5.07	8.14	1174	34.21 ± 0.050
30.5	5.76	2.91	4.50	3.87	4.09	5.92	1318	27.05 ± 0.041
mean[b]	8.32	4.35	6.35	5.77	7.01	6.24		

n = total number of samples for all life stages.

[a] mean of combined life stages (egg, first, second, third, fourth, fifth)

[b] mean of each individual stage

Table 1.13. Regression of development rates (1/d) of *Euschistus conspersus* on temperature and estimates of development thresholds (T_0) and degree-day (DD) totals for each life stage.

Stage	n	Slope	Y Intercept	r^2	T_0C	DD
Egg Stage	1657	0.1121	-0.1121	0.9222	11.80	105.26
1st Instar	1278	0.0193	-0.2411	0.9321	12.49	51.81
2nd Instar	695	0.0116	-0.1276	0.9062	11.00	86.21
3rd Instar	454	0.0146	-0.1823	0.9263	12.48	68.49
4th Instar	284	0.0168	-0.2600	0.9590	15.47	59.52
5th Instar	176	0.0105	-0.1535	0.9888	14.62	94.34

n = number of samples

CHAPTER 2

EGG PARASITES OF PENTATOMIDAE IN CENTRAL WASHINGTON FRUIT PRODUCING REGIONS

INTRODUCTION

Eggs of stink bugs are attacked by hymenopterous parasitoids in the genera *Telenomous*, *Trissolcus*, and *Ooenycyrtus*. Parasitoids have been reported attacking *Nezara viridula* (Linneaus), *Acrosternum hilare* (Say), *Euschistus servus* (Say), and *Euschistus variolarius* (Palisot) in soybean and alfalfa (Bushman et al. 1980, Okuda et al. 1988, Orr et al. 1986, and yeargan 1979). Parasitoids of stink bug eggs occur in fruit orchards in the eastern United States and California; however, they have not been reported in Washington. Uncultivated vegetation outside of fruit orchards may play a role in managing populations of stink bug pest species because overwintering adults lay eggs in these habitats (Borden et al. 1952). Research conducted during 1996 and 1997 in fruit producing regions of north-central Washington determined the presence and species of wasps attacking stink bug eggs and parasitoid activity throughout the season.

MATERIALS AND METHODS

Egg parasitism - 1996

Three sites, Entiat, Orondo, and Manson, were monitored from 16 May to 23 August , 1996, to determine the presence and seasonal activity of stink bug egg parasitoids. These sites were the same as those described in Chapter 1. *Euschistus conspersus* egg masses which were laid on waxed paper in the laboratory were obtained from a colony maintained at the WSU-TFREC. Sections (strips) of waxed paper containing individual masses, each containing 10 to 14 eggs, were removed. Egg masses were stored at 10^{o}C until ready for placement in the field. The development rate of *E. conspersus* eggs was determined to be essentially zero at temperatures below 12^{o}C (McGhee and Brunner unpublished 1995).

Sentinel egg masses were randomly placed on leaves of fruit trees on orchard borders and native vegetation near orchard borders at each site. Paper strips containing *E. conspersus* egg masses were attached to the underside of vegetation with a hand-held paper stapler. After seven days, egg masses were collected, placed in small plastic petri dishes (Falcon® #1006 50 x 9 mm), and returned to the laboratory where they were incubated at 27^{o}C in a long-day photoperiod (16h:8h, L:D) until parasitoids or stink bugs emerged. Missing egg masses were considered lost to predation. The level of parasitism each week was based on the number of actual sentinel egg masses recovered from a Site. For analysis, samples for each two-week period were combined for each site. Mean parasitism (and standard error) was determined for each Site, by sample period, and by host vegetation, to show the activity of parasitoids.

Egg parasitism - 1997

A survey of stink bug egg parasitoid seasonal activity was conducted at three sites around Lake Chelan (Craft, Dole, and Naumes) from 12 June to 22 September 1997. These sites were described in Chapter 1. Egg masses of *Perillus bioculatus* (StÂl), a predatory stink bug, were obtained from a colony maintained at the USDA-APHIS-PPQ Mission Biological Control Center in Mission, Texas. *Perillus bioculatus* egg masses were laid on brown paper and shipped weekly to Wenatchee. Egg masses were stored at 10°C until ready for placement in the field.

The same methods used in 1996 to distribute, collect, and incubate sentinel egg masses of *E. conspersus* were repeated in 1997 for *P. bioculatus* egg masses. Missing egg masses were considered lost to predation and the level of parasitism each week was based on the number of actual egg masses recovered from a Site. For analysis, samples for each two-week period were combined for each site. Mean parasitism (and standard error) was determined for each Site, by sample period, and by host vegetation, to show the activity of the parasitoids.

Parasitoids recovered were point mounted. Samples of these specimens were sent to The Ohio State University Department of Entomology to be identified by Dr. Norman F. Johnson. Voucher specimens were retained in the James Entomological Collection at Washington State University and by Dr. Johnson.

RESULTS AND DISCUSSION

Five species of parasitoids were reared from *E. conspersus* eggs (Table 2.1). This represents the first report of parasitoids attacking eggs of Pentatomidae in Washington. Four of the species are in the family Scelionidae. These species, *Telenomous podisi* Ashmead, *Trissolcus cosmopeplae* (Gahan), *Trissolcus euschisti* (Ashmead), and *Trissolcus utahensis* (Ashmead) were reported attacking the eggs of stink bugs in other regions of North America (Borden et al. 1952, Whitmarsh 1917, Mundinger and Chapman 1932, Jubb and Watson 1971). The fifth species, an encyrtid, has also been reported attacking the eggs of stink bugs (Bushmann and Whitcomb 1980). These parasitoids appear to attack a wide range of stink bug species. There is some evidence indicating that parasitoids partition habitat in which stink bug egg masses are found and that biological control efforts should be concentrated on parasitoid species found in the habitat of preference (Yeargan 1979, Okuda and Yeargan 1988).

There were differences in the mean number of eggs parasitized according to the date they were placed in the field (Table 2.2). In 1996, mean egg parasitism ranged from 63.25% in early July to 12.7% in late August. High rates of parasitism in July corresponded with the highest level of oviposition activity by *E. conspersus.* Parasitoids were active on the first date sentinel egg masses were placed in the field in both years. There was an increase in the percent of eggs parasitized from 14 June through 12 July, 1996. Beginning in midsummer through late August, there was a gradual decline in the percentage of eggs parasitized. In 1997 this pattern was repeated. Parasitism increased from 42% in early June and increased to 62% in early July. The percent parasitism gradually declined to 0.0% in October. The period of peak parasitoid activity was well synchronized to stink bug development. Stink bug oviposition, especially that of *E. conspersus*, primarily occurs during June and July in Washington and coincided with periods that had the highest incidence of parasitism in this study.

Surveys conducted during 1996 and 1997 showed that egg parasitoids were active on many different plants used as hosts by stink bugs and that their activity on these plants was similar. High rates of parasitism occurred on bitterbrush, red-osier dogwood, poplar, apple, and mullein (Tables 2.3 and 2.4). Phenology studies indicate that mullein was one of the primary plants used by *E. conspersus* for oviposition. This may be a reflection of the high percentage of parasitism on this plant, but it does not explain the high rates of parasitism on other vegetation. The parasitoids may just be very active searchers of potential habitats where stink bug eggs are found, or other factors such as volatiles given off by egg masses or stink bug pheromones might provide cues directing the parasitoids where to search. Tachinid flies are reported using heteropteran pheromones as host-finding kairomones (Aldrich et al. 1989). The stink bugs *E. conspersus* and *C. ligata* frequently occur on other plant types in Washington associated with high rates of egg parasitism and, while egg masses are occasionally found on these plants, the incidence is low when compared to mullein.

Although parasitoids have been reported attacking the eggs of stink bugs known to cause injury in tree fruits, little is known about wasp biology or their potential to limit populations of their hosts. Most studies on the population dynamics of stink bugs and natural enemies have been conducted in alfalfa and soybean (Yeargan 1979, Jones et al. 1983, and Orr et al. 1986). In these studies, even when parasite activity resulted in high mortality levels, ~50%, they were unable to maintain stink bug populations below economic thresholds in soybean (Orr et al. 1986). In Washington, all of the sites where high levels of parasitism were observed have suffered high levels of fruit injury. While egg parasitoids obviously have some effect on stink bug populations, it seems doubtful that natural enemies can be relied upon to provide the primary control of stink bug populations in Washington fruit growing regions. It may be possible to enhance the biological control of stink bugs in native habitats with augmentation of parasitoids; however, difficulties in rearing host eggs to mass produce parasitoids would be a major detriment to this approach. Host plants associated with stink bug oviposition may have the potential to be used in a trap cropping strategy to increase the effectiveness of egg parasitoids within a region. The role of different species of egg parasitoids requires additional study if any of these are to be used in future biological control programs of stink bugs.

Table 2.1. Wasp parasites of the egg stage of *Euschistus conspersus* Uhler

Family	Genus species
Scelionidae	*Trissolcus cosmopeplae* (Gahan)
Scelionidae	*Trissolcus euschisti* (Ashmead)
Scelionidae	*Trissolcus utahensis* (Ashmead)
Scelionidae	*Telenomous podisi* Ashmead
Encyrtidae	*Ooenycyrtus sp.*

Table 2.2. Percent parasitism of the egg stage of Pentatomidae in Chelan County,
Washington, in 1996 and 1997.

Year	Date	n	Mean # eggs/mass ± SEM	Mean # parasites ± SEM	Mean % parasitism
1996	14 June	25	11.96 ± 0.558	2.72 ± 1.014	22.74
	28 June	31	12.42 ± 0.724	4.96 ± 1.107	39.80
	12 July	32	14.83 ± 1.009	9.38 ± 1.310	63.25
	26 July	49	14.49 ± 0.775	5.89 ± 1.05	40.65
	12 August	14	16.50 ± 1.940	8.64 ± 3.166	52.36
	23 August	23	13.70 ± 0.888	1.74 ± 0.761	12.70
1997	12 June	30	20.33 ± 1.317	8.70 ± 1.670	42.79
	26 June	54	19.89 ± 1.089	7.62 ± 1.0265	38.31
	10 July	56	20.93 ± 0.997	13.07 ± 1.462	62.24
	7 August	57	12.19 ± 0.709	3.68 ± 0.890	30.18
	21 August	46	11.00 ± 0.597	2.11 ± 0.587	19.18
	4 Sept.	12	11.17 ± 1.608	0.67 ± 0.666	5.99
	18 Sept.	18	11.28 ± 1.201	2.11 ± 0.831	18.70
	2 October	11	15.00 ± 1.967	0.00 ± 0.000	0.00

n = number of egg masses

Table 2.3. Summary of percent egg parasitism *of E. conspersus* by Site, host plant,

and month during 1996.

Site	Plant	n	June	n	July	n	August
Cashmere	apple	51	31	109	21	--	--
Cashmere	bitterbrush	--	--	43	--	--	--
Cashmere	cherry	--	--	13	--	--	--
Cashmere	pear	144	22	116	25	--	--
Cashmere	poplar	--	--	85	70	--	--
Entiat	bitterbrush	--	--	70	--	--	--
Entiat	blackberry	--	--	--	--	35	0
Entiat	pear	73	19	62	19	56	23
Entiat	poplar	--	--	34	23	25	0
Entiat	red-osier dogwood	81	62	194	70	171	30
Entiat	rose	--	--	--	--	46	43
Entiat	thimbleberry	--	--	10	20	11	0
Manson	bitterbrush	79	81	154	50	60	35
Manson	blackberry	--	--	28	30	9	0
Manson	currant	7	0	14	0	--	--
Manson	mullein	28	46	40	57	11	0
Manson	apple	6	0	41	24	14	0
Manson	poplar	14	0	13	100	--	--
Manson	red-osier dogwood	--	--	8	100	--	--
Manson	serviceberry	--	--	40	100	--	--
Orondo	apple	14	0	14	0	17	0
Orondo	bitterbrush	40	0	32	100	74	81
Orondo	currant	33	57	27	18	12	0
Orondo	red-osier dogwood	27	0	26	53	50	4

n = number of eggs

no data, stink bug eggs not available for distribution.

Table 2.4. Summary of percent egg parasitism *of Perillus bioculatus* by Site, host plant, and month during 1997.

Site	Host plant	n	Jun	n	Jul	n	Aug	n	Sept	n	Oct
aft	bitterbrush	263	44	139	43	166	26	20	40	28	0
ole	bitterbrush	251	24	166	72	248	30	77	0	29	0
aumes	bitterbrush	217	67	217	63	276	12	74	0	28	0
aft	blackberry	51	39	44	93	30	0	9	0	0	0
ole	blackberry	111	38	82	68	90	13	19	0	9	0
aumes[a]	currant	189	53	124	87	136	57	--	--	16	0
aft	mullein	278	11	132	71	195	28	57	38	6	0
ole	mullein	139	47	44	36	127	45	40	40	34	0
aumes	mullein	92	64	82	25	78	0	13	0	15	0
ole[b]	poplar	16	0	46	0	34	0	--	--	--	--
ole[b]	serviceberry	11	0	41	92	41	34	--	0	--	0
aft[c]	cherry	47	23	46	52	32	0	28	0	--	0

n = number of eggs

-- no data, stink bug eggs not available for distribution.

[a] Plant was only present at Naumes orchard site

[b] Plant was only present at Dole orchard site

[c] Plant was only present at Craft orchard site

CHAPTER 3

CHARACTERIZATION OF STINK BUG FRUIT INJURY, DAMAGE PATTERNS IN ORCHARDS, AND TRAP EVALUATION

INTRODUCTION

Stink bugs feeding on fruits cause visible deformities which result in downgrading or cullage. Severe infestations may result in fruit drop before harvest (Rings 1957). Feeding results in cat-facing of stone fruits (Whitmarsh 1917, Rings 1957, Woodside 1946), cottony spot in pear (Wilks 1964), and dark sunken areas on apple (Phillips and Howell 1979). Although stink bug injury has been described on pome fruits in many regions, it has not been characterized in Washington. To describe stink bug injury on apple, and thereby verify the cause of such fruit damage in Washington, studies were conducted at the Tree Fruit Research and Extension Center in Wenatchee, Washington. The level and pattern of stink bug injury to apple was also evaluated in several north-central Washington orchards subject to annual invasions of stink bugs.

Monitoring of crops provides valuable information on insect pests. The major objectives of surveillance are detection of species presence, determination of population density, dispersion, and dynamics (Pedigo 1996). This information is used to develop and implement successful management strategies. Population assessment systems used in pest management fall into two categories; direct or indirect. Direct assessment systems involve measuring the density of a pest's life stage that is causing damage to the crop. This is usually accomplished by sampling the stage through direct observation, for example, collecting leaves and counting aphids present or examining shoots of apple trees and counting the number of leafroller larvae present. Indirect assessment systems involve measuring a pest's life stage but not one necessarily associating it with crop damage. This is usually accomplished by employing traps or nets to collect the insect and then making inferences as to the numbers collected and the pest's population in the crop. Trapping is one of the most valuable tools used to gather data on crop pests. Chemical attractants, such as mating or aggregation pheromones, are often used to enhance trap catch.

Stink bugs are sporadic pests of deciduous fruits that spend most of their life cycle outside the orchard. Invasions into orchards typically occur in late summer after adults are produced; however, the annual timing of when invasions begin and where they will occur geographically is poorly understood. It is impractical to monitor orchards visually for presence of stink bugs because they are very elusive and usually present in relatively low numbers, at least at the beginning of invasion events. Development of a reliable trapping method would greatly reduce the time and money required to monitor for these pests and improve the ability to predict orchards at risk from stink bug invasions, and delineate the time when invasion events begin. In 1997, different trap types were evaluated in north-central Washington for their relative ability to capture stink bugs in orchards and native habitats bordering orchards.

MATERIALS AND METHODS

Fruit injury and Characterization

In 1997, the characterization of stink bug injury to apple was determined at the WSU-TFREC in Wenatchee. Three treatments, *E. conspersus* Uhler adults, *C. ligata* (Say) adults, and a control with no stink bugs, were used to characterize the feeding injury on two apple varieties, Delicious and Gala. Five adult stink bugs of a given species were caged on 2-3 apples within a wire mesh sleeve cage. Each treatment was replicated five times for each stink bug species and fruit variety. Cages were removed after seven days, and the number of live and dead stink bugs was recorded. After removing sleeve cages, limbs were sprayed with Carzol 92 SP at a rate of at 1.135 g/gal (equivalent to 0.25 lb/100 gal) using a garden-type hand sprayer. This insecticide was applied only to the local area where the stink bugs had been caged to kill any surviving bugs and to prevent other insects from inflicting damage. Injury was characterized and photographed on each variety for all three treatments 14 days after caging.

Damage pattern in orchards

The pattern of fruit injury in apple orchards was evaluated during 1996 and 1997. One block in the Dole Site and two blocks in the Naumes Site were examined in 1996. In 1997, three blocks in the Dole Site were sampled because injury from the previous year suggested a large stink bug population was resident in the area. One block was examined at both the Naumes and Craft Sites during 1997. These Sites were the same as those described in Chapter 1. Fifty fruits were sampled from each tree in 1996. Four trees in the perimeter row (Row #1) and four trees at four successive intervals inside the orchard were sampled in each orchard in early September just prior to harvest.

In 1997, 50 fruits were again sampled from each tree, on five trees in the perimeter row and at two intervals inside the orchard. The number of injured fruits per tree was recorded.

Trap evaluation

Four trap designs were evaluated for their relative effectiveness in capturing stink bugs in Chelan County, Washington between 1 June and 8 September, 1997. Traps designs were 1) Jug trap - a modified 3.8 liter transparent plastic jar with 2 wire mesh funnels 13 cm diameter tapering to 1.5 cm diameter inserted in opposite sides of the container, 2) Tube trap - a large transparent plastic tube 20 cm long and 10 cm in diameter with two wire mesh funnels 10 cm diameter tapering to ca. 1.5 cm diameter inserted in opposite ends, 3) Weevil trap - a transparent plastic tube 16 cm long with a 9 cm diameter and two 4 cm openings centered on each end (modified Hercon boll weevil trap), and 4) Cone trap - a boll weevil trap (USDA type) consisting of a wire mesh screen funnel 11.5 cm diameter tapering to 1.5 cm diameter with a small transparent plastic collection tube 5.5 cm long by 5.5 cm diameter attached to the tapered end of the funnel (Fig. 3.1). Each trap was baited with a lure, a sleeve-type rubber septum, containing 20 mg of methyl (2E, 4Z)-decadienoate, a male-specific volatile of *E. conspersus* (Aldrich et al. 1991). Each septum was suspended in the middle of a trap. Each trap also contained a small block of pest strip (Dichlorvos) in relation to the trap size: Cone = 0.5 cm^3, Tube = 1 cm^3, Weevil = 1 cm^3, and Jug = 1.5 cm^3.

Traps were placed in fruit trees in the border row of an orchard and in vegetation of native habitats near the orchard border. In the orchard, traps were attached with twine to main scaffold limbs of fruit trees in the perimeter rows 1.5 m above the ground. In native habitats, traps were placed 30 m from the orchard border in bitterbrush, mullein, currant, or serviceberry. All traps were spaced 20 m apart both inside and outside of the orchard. Traps were checked and the positions rotated twice each week. The number, life stage, and species were recorded for each trap each sample period. Lures were replaced weekly. Each treatment (trap) was replicated six times in each habitat. Data were evaluated using analysis of variance (Super ANOVA, Abacus Concepts 1989) separately for traps placed in orchards and native habitats. Where appropriate, trapping means were separated using Fisher's protected LSD.

RESULTS AND DISCUSSION

Fruit injury and Characterization

All Delicious apples caged with *E. conspersus* or *C. ligata* displayed signs of injury. Small, dark depressions, ranging in diameter from 1 mm to 1 cm, were visible on the exterior of the fruit surface as seen in Figure 3.2. Injury was sustained on the upper and lower hemispheres of the fruit. Peeling the skin of the fruit revealed light to medium brown discoloration of the flesh that extended into the center of the fruit 1-5 mm (Fig. 3.3). Gala apples showed no external signs of injury two weeks after caging. Ten fruits from each treatment were placed in cold storage (2^{o}C) for two weeks. The remaining fruits were peeled to examine for injury. Injured flesh of the Gala was very slightly discolored, appearing creamy white against the normally light yellow-colored flesh (Fig. 3.4). Gala fruit placed in cold storage did not develop any external symptoms of stink bug injury. Control fruit of both varieties showed no signs of damage.

Delicious varieties incur visible damage on the exterior that extends into the flesh of the fruit, while there was no visible external signs of damage to the Gala varieties in our study (Table 3.1). Different responses might be explained by variety, physiology, or stage of fruit development. Caged tests were conducted when Gala were fully mature. Delicious apples were still growing and ripening at that time. Injury on Delicious apples is observed during mid or late August, at which time the Gala apples have already been harvested in most years. Stink bugs invading orchards from uncultivated areas may arrive too late to cause injury, or for visible signs of injury, to become apparent on Gala apples.

Damage by *E. conspersus* and *C. ligata* adults on Delicious apples was similar in appearance. Pears attacked by *A. hilare* and *E. variolarius* exhibited dimpling on the fruit surface and white cottony pockets in the flesh (Mundinger and Chapman 1932, and Wilks 1964). Brown, tobacco-colored droplets were detected on some of the apples injured by stink bugs. These droplets were described as stink bug excrement by Borden (1952).

Examination of the spatial distribution of stink bug injury in orchards during 1996 revealed high levels of fruit damage along the border row (Table 3.1). The mean number of fruit damaged in the Dole upper and lower Sites was 15 and 9.75, respectively, out of 50 in trees examined along the border, decreasing to 2.5 out of 50 in trees 60 feet into the orchard. The same pattern was observed in two different blocks in the Naumes Site (Table 3.1). The East Naumes Site had a mean of 14.25 out of 50 injured fruits in border trees and only 1.0 of 50 injured fruits in trees 80 feet into the orchard. The West Naumes Site had a mean of 15 of 50 injured fruits in the border trees and 0.2 of 50 injured fruits on trees 80 feet into the orchard. In all orchards, the decline in fruit injury from the border to the fifth row was not gradual, but was very abrupt. Each Site sustained less than 10% injury by the second row or approximately 20 feet in to the orchard..

Injury patterns in 1997 were similar to those in 1996 (Table 3.2). Border rows sustained greater damage than the interior rows. Three blocks in the Dole Site, Northeast, Northwest, and Southwest, sustained means of 38.4, 17.8, and 8.6 fruits injured, respectively, out of 50 in the border rows and 6.8, 1.8, and 0.0 mean fruits injured, respectively, out of 50 in the third interior row. The mean numbers of damaged fruits in the border and interior rows was 15.6 and 0.8 fruits, respectively, out of 50 at the Craft Site and 19.6 and 0.4, respectively, out of 50 at the Naumes Site.

The injury pattern for 1996 and 1997 suggests a strong border effect. Migrating stink bug adults move to orchard borders and stop to feed. Where the highest levels of fruit injury occurred on the borders, and where the blocks were also relatively small, e.g., the Dole Northeast Site in 1997, higher levels of fruit injury were noted in the interior trees. It may be possible to prevent or greatly reduce fruit damage in an orchard by keeping active insecticide residues on rows bordering native habitats. Trap evaluation studies in 1997 indicate high numbers of stink bugs in the perimeter rows of orchards where high levels of fruit injury were noted. Traps might, therefore, provide information that would assist the crop consultant or grower in determining the time to initiate protective sprays and in determining which orchards and what borders were at risk from stink bugs.

Trap evaluation

Nymphs and adults of *E. conspersus* and *C. ligata* were captured in all four trap designs. A total of 637 stink bugs was captured, 497 *E. conspersus* and 140 *C. ligata* in 1997. Greater numbers of adult stink bugs were caught in the traps with the exception of the Cone trap where more nymphs were captured. In native habitats the mean number of adult *E. conspersus* and *C. ligata* captured in each trap design was statistically significant (F = 8.111 and 3.298, respectively; df = 3; P < 0.05). In the same habitat, however, there was no difference between the number of nymphs for either species captured in different trap designs. The number of *E. conspersus* adults captured in the Cone and Weevil traps was not significantly different and neither was the number captured in the Tube and Weevil traps, however, adult *E. conspersus* captured in the Jug were significantly different from all of these. The mean number of *C. ligata* adults captured in the Cone and Weevil traps were not significantly different from one another, additionally, captures in the Tube trap was not significantly different from the latter two or the Jug trap. The Jug trap captured significantly more *C. ligata* adults compared to the Cone and Weevil traps (Table 3.4).

Trap performance in orchards was similar to that of traps placed in native habitats. However, statistically significant differences were found for the mean number of *E. conspersus* adults in different traps (F = 12.371, df = 3, P < 0.05). Trap captures for these adults show that the Cone and Weevil trap were not significantly different, but captured significantly less adult bugs than captures in the Jug and Tube traps. Captures in the Jug and Tube traps were not significantly different (Table 3.3).

The number of adult stink bugs captured in the orchard traps was not correlated with fruit injury. Mean trap catch was very low for even the best performing trap, the Jug. Mean seasonal catch of *E. conspersus* in all orchards combined, increased during August, and this coincided with stink bug invasions from native areas into the orchard. Although there were statistical differences in trap performance, these did not appear to indicate the level of fruit damage sustained at different orchards.

Many stink bugs were found on or near the traps during this study but were not included in trap evaluation. Differences in trap performance are likely attributed to trap design. Possibly, with improved trapping methods, injury levels can be correlated with trap catch. Also, stink bug populations, and therefore their invasions into orchards, may be more accurately monitored with improved trap design or attractants used.

The attractant used in trap evaluations, Methyl (2E, 4Z)-decadienoate, was determined to be a male- specific volatile of the genera *Euschistus* (Aldrich et al. 1991). Females, males, adults, and nymphs of *Euschistus sp*. are attracted to this volatile. This chemical is very similar to the so-called pear ester, Ethyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). Possibly one of the reasons stink bugs are attracted to pome fruits is due to this analogy. Further evaluation of trap design, attractants, and understanding of stink bug behavior and physiology would help in developing better monitoring tools.

Table 3.1. Mean number of fruit injuries in apple orchards in 1996 (Mean ± SEM).

Location	n	Border (1st Row)	2nd sample interval into orchard	3rd sample interval into orchard	4th sample interval into orchard	5th sample interval into orchard
Dole Upper[a]	4	15.0 ± 4.5	4.5 ± 1.5	6.0 ± 2.8	3.0 ± 1.4	2.5 ± 1.0
Dole Lower[a]	4	9.7 ± 4.5	0.7 ± 0.7	0.2 ± 0.2	0.5 ± 0.5	2.7 ± 1.9
Naumes East[b]	4	14.2 ± 7.7	1.5 ± 1.5	0.2 ± 0.2	0.7 ± 0.7	1.0 ± 0.7
Naumes West[b]	4	15.0 ± 2.6	4.2 ± 1.1	3.0 ± 0.4	2.4 ± 1.6	0.2 ± 0.2

[a] distance (ft) between sample interval into orchard = 15 feet

[b] distance (ft) between sample interval into orchard = 20 feet

Table 3.2. Mean number of fruit injuries in apple orchards in 1997 (Mean ± SEM).

Location	n	Border Percent Fruit injury	2nd sample interval Percent Fruit injury	3rd sample interval Percent Fruit injury
Craft[a]	5	15.6 ± 3.6	6.0 ± 3.1	0.8 ± 0.8
Dole Northeast[a]	5	38.4 ± 3.8	18.4 ± 0.7	6.8 ± 0.9
Dole Northwest[a]	5	17.8 ± 2.8	6.0 ± 2.8	1.8 ± 0.8
Dole South[a]	5	8.6 ± 3.2	1.6 ± 0.6	0.0 ± 0.0
Names[b]	5	19.6 ± 4.1	3.4 ± 1.4	0.4 ± 0.2

n = number trees, 50 fruit per tree sampled.

[a] distance (ft) between sample interval into orchard = 15 feet

[b] distance (ft) between sample interval into orchard = 20 feet

Table 3.3. Mean number of *E. conspersus* and *C. ligata* captured per trap in orchard habitats in Chelan County,
Washington, 1997.

es	Trap	n	June Mean ± SEM	n	July Mean ± SEM	n	August Mean ± SEM	n	Sept. Mean ± SEM	Sea Mean[b]
ersus[a]	Cone	45	0.08 ± 0.04	29	0.00	29	0.06 ± 0.06	11	0.81 ± 0.12	0.18 ±
ersus[a]	Weevil	45	0.13 ± 0.06	29	0.10 ± 0.05	29	0.10 ± 0.05	11	0.27 ± 0.19	0.19 ±
ersus[a]	Tube	45	0.31 ± 0.12	29	0.00	29	0.44 ± 0.13	11	0.18 ± 0.18	0.75 ±
ersus[a]	Jug	45	0.33 ± 0.14	29	0.24 ± 0.09	29	0.68 ± 0.22	11	0.45 ± 0.24	0.72 ±
ersus[n]	Cone	45	0.00	29	0.20 ± 0.10	29	0.06 ± 0.04	11	0.00	0.23 ±
ersus[n]	Weevil	45	0.00	29	0.33 ± 0.14	29	0.00	11	0.00	0.14 ±
ersus[n]	Tube	45	0.00	29	0.46 ± 0.27	29	0.20 ± 0.10	11	0.00	0.33 ±
ersus[n]	Jug	45	0.00	29	0.46 ± 0.21	29	0.16 ± 0.10	11	0.00	0.28 ±
ta[a]	Cone	45	0.00	29	0.00	29	0.06 ± 0.04	11	0.00	0.01 ±
ta[a]	Weevil	45	0.02 ± 0.02	29	0.06 ± 0.04	29	0.17 ± 0.07	11	0.18 ± 0.01	0.03 ±
ta[a]	Tube	45	0.11 ± 0.07	29	0.00	29	0.24 ± 0.12	11	0.36 ± 0.15	0.08 ±
ta[a]	Jug	45	0.22 ± 0.16	29	0.10 ± 0.05	29	0.31 ± 0.14	11	0.27 ± 0.27	0.11 ±
ta[n]	Cone	45	0.00	29	0.10 ± 0.05	29	0.16 ± 0.08	11	0.00	0.00 ±
ta[n]	Weevil	45	0.00	29	0.60 ± 0.37	29	0.10 ± 0.05	11	0.00	0.00 ±
ta[n]	Tube	45	0.00	29	0.06 ± 0.04	29	0.03 ± 0.03	11	0.00	0.01 ±
ta[n]	Jug	45	0.00	29	0.23 ± 0.14	29	0.53 ± 0.17	11	0.00	0.00 ±

[a] Adult stage

[n] Nymph stage

[b] Mean trap catch for season.

Means within a species and life-stage followed by the same letter are not significantly different, (Fisher's protected LSD, $P < 0.05$)

Table 3.4. Mean number of *E. conspersus* and *C. ligata* captured per trap in native habitats in Chelan County,
Washington, 1997.

es	Trap	n	June Mean ± SEM	n	July Mean ± SEM	n	August Mean ± SEM	n	Sept. Mean ± SEM	Seas Mean SE
sus[a]	Cone	45	0.11 ± 0.04	29	0.13 ± 0.06	29	0.27 ± 0.14	11	0.36 ± 0.20	0.06 ±
sus[a]	Weevil	45	0.20 ± 0.08	29	0.10 ± 0.07	29	0.31 ± 0.12	11	0.18 ± 0.18	0.12 ±
sus[a]	Tube	45	0.93 ± 0.24	29	0.48 ± 0.25	29	0.96 ± 0.21	11	0.45 ± 0.28	0.25 ±
sus[a]	Jug	45	0.84 ± 0.21	29	0.65 ± 0.20	29	0.62 ± 0.18	11	0.27 ± 0.19	0.42 ±
sus[n]	Cone	45	0.00 ± 0.00	29	0.33 ± 0.22	29	0.62 ± 0.38	11	0.00 ± 0.00	0.06 ±
sus[n]	Weevil	45	0.00 ± 0.00	29	0.43 ± 0.17	29	0.13 ± 0.08	11	0.00 ± 0.00	0.08 ±
sus[n]	Tube	45	0.00 ± 0.00	29	0.86 ± 0.37	29	0.48 ± 0.15	11	0.00 ± 0.00	0.16 ±
sus[n]	Jug	45	0.00 ± 0.00	29	0.70 ± 0.30	29	0.37 ± 0.21	11	0.08 ± 0.08	0.16 ±
ta[a]	Cone	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.03 ± 0.03	11	0.09 ± 0.09	0.01 ±
ta[a]	Weevil	45	0.00 ± 0.00	29	0.03 ± 0.03	29	0.03 ± 0.03	11	0.18 ± 0.12	0.08 ±
ta[a]	Tube	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.20 ± 0.12	11	0.36 ± 0.24	0.13 ±
ta[a]	Jug	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.27 ± 0.12	11	0.54 ± 0.31	0.21 ±
ta[n]	Cone	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.00 ± 0.00	11	0.00 ± 0.00	0.08 ±
ta[n]	Weevil	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.00 ± 0.00	11	0.00 ± 0.00	0.17 ±
ta[n]	Tube	45	0.00 ± 0.00	29	0.06 ± 0.06	29	0.00 ± 0.00	11	0.00 ± 0.00	0.02 ±
ta[n]	Jug	45	0.00 ± 0.00	29	0.00 ± 0.00	29	0.00 ± 0.00	11	0.00 ± 0.00	0.19 ±

[a] Adult stage
[n] Nymph stage
[b] Mean trap catch for season

Means within a species and life-stage followed by the same letter are not significantly different, (Fisher's protected LSD, $P < 0.05$)

Figure 3.1. Stink bug traps from left to right: Cone, Weevil, Jug, and Tube.

Figure 3.2. Stink bug injury on Delicious apple, exterior.

Figure 3.3. Stink bug injury on Delicious apple, interior.

Figure 3.4. Stink bug injury on Gala apple.

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APPENDIX

Host plants of stink bugs (Pentatomidae) in north-central Washington.

Common Name	Family	*Genus species*
Apple	Rosaceae	*Pyrus*. L.
Asparagus	Liliaceae	*Asparagus officinalis* L.
Baby's breath	Caryophyllaceae	*Gypsophila paniculata* L.
Balsamroot	Asteraceae	*Balsamorhiza sagittata* (Pursh)
Big-leaf maple	Aceraceae	*Acer macrophyllum* Pursh
Bitterbrush	Rosaceae	*Purshia tridentata* (Pursh)
Blackberry	Rosaceae	*Rubus* L.
Cheat grass	Poaceae	*Bromus* L.
Cherry	Rosaceae	*Prunus* L.
Current	Anacardiaceae	*Rhus trilobata* Nutt.
Dalmation toadflax	Scrophulariaceae	*Linaria genistifolia* L.
Elderberry	Caprifoliaceae	*Sambucus* L.
Mullein	Scrophulariaceae	*Verbascum thapsus* L.
Pear	Rosaceae	*Pyrus* L.
Poplar	Salicaceae	*Populus* L.
Rabbitbrush	Asteraceae	*Chrysothamnus* L.
Red-osier dogwood	Cornaceae	*Cornus stolonifera* Michx.
Russian knapweed	Asteraceae	*Centaurea repens* L.
Sage	Asteraceae	*Artemisia* L.
Serviceberry	Rosaceae	*Amelanchier alinifolia* Nutt.
Snowberry	Caprifoliaceae	*Symphoricarpos occidentalis* Hook.
Sumac	Anacardiaceae	*Rhus glabra* L.
Thimbleberry	Rosaceae	*Rhubus parviflorus* Nutt.
Vetch	Fabaceae	*Vicia* L.
Wild Rose	Rosaceae	*Rosa* L.